Nuclear INFORMATION

Greater St. Louis Citizens' COMMITTEE FOR NUCLEAR INFORMATION

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THE DETECTION OF NUCLEAR TESTS

THE EFFORT, over the past 22 months, to conclude a nuclear test ban treaty has involved a complicated mixture of scientific fact, scientific theory, and international politics. To help the reader unscramble the problem, *Nuclear Information* presents in this issue an explanation of the scientific facts and theories that affect a controlled test ban agreement.

The main questions are: How well can nuclear tests be detected? To what extent can tests be concealed?

Two kinds of answers can be given: One is based on actual experience with the 200-odd explosions of nuclear weapons to date; the second is a theoretical estimate of what modern science can do on the one hand to improve detection, and on the other hand, to make concealment more effective.

Surface Explosions are Easy to Detect

Of the 200 or so nuclear explosions carried out by the U.S., U.K., U.S.S.R., and France between 1945 and 1960, all but a few were exploded at or near the surface of the earth. These surface explosions were readily detected in all parts of the world because they produced radioactive fallout that was picked up by instruments that measure the radioactivity of rainfall and dust around the globe.

The time elapsed since an explosion can be calculated from the kinds of radioactive elements found in the fallout. This information and the wind pattern can be fitted together to reveal when and where the explosion took place. In this way, the U.S. has monitored Russian explosions, Russia has monitored U.S. explosions, and the Japanese have reported both. There is complete agreement that surface explosions of nuclear weapons cannot be concealed from anyone.

The High Ones can be Detected Too

Explosions at a great distance above the surface of the earth introduce a new problem of detection. On August 1 and 12, 1958, the U.S. exploded nuclear bombs above Johnston Island in the central Pacific at heights of about 50 and 25 miles. The explosions were not announced, and at first appeared to have gone unnoticed; but they were in fact detected because they intruded on a scientific experiment then underway -- the International Geophysical Year. How this happened is described in a scientific report by Dr. Sadami Matsushita of the University of Colorado High Altitude Observatory.[1]

Part of the IGY program consisted of measurements, at a number of scientific stations throughout the world, of fluctuations in the magnetic properties of the earth's atmosphere. When IGY scientists examined their records for August, they discovered that on August 1 and 12, unusual effects occurred which indicated that there were artificial magnetic storms and radiation in the Pacific area on those dates. Such effects could only have resulted from nuclear explosions. From these observations, Dr. Matsushita was able to calculate the approximate height of the explosions and when they occurred.

Actually, an even simpler method for detecting these explosions exists, for the magnetic effects of the explosion caused a blackout of radio communication in the area.[1]

On August 27 and 30, and September 6, 1958, the U.S. conducted explosions over the south Atlantic at a height of about 290 miles. Dr. Matsushita points out that these explosions caused an aurora which was observed near the Azores, and that charged particles due to the explosions were picked up by one of the U.S. satellites, Explorer IV. Although the IGY stations were not equipped to pick up geomagnetic changes due to explosions at such heights, Dr. Matsushita says that stations equipped with the suitable instruments (sub-audio-frequency magnetometers) would probably have detected these explosions.

Detecting the Underground Blasts

Detection of explosions beneath the surface of the ground is still a source of difficulty. To detect such explosions we rely on the seismograph. This instrument, which is used to detect earthquakes, can also record the shock wave produced by a powerful weapon exploding underground.

In September 1957, the U.S. exploded a single small 1.7 kiloton (1700 ton) nuclear bomb underground in Nevada (Rainier). The question of how far away from the explosion site in Nevada the test was picked up by seismographs, was a matter of some confusion: the AEC initially stated that the greatest distance was about 200 miles, but later they stated that it was about 2000 miles. In 1958, several more underground explosions, called Hardtack II, were carried out in Nevada; this time, seismographic stations all over the world were alerted, and made careful records during the explosions.

All past nuclear explosions have apparently caused observable shock waves at some distance from the test site. But this is not the whole story. It is one thing to find in the record of an insturment an effect that can be attributed to an explosion that you *know* took place; it is a more difficult propo-

(continued on page 2)

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CHRONOLOGY

Sept. 19, 1957	1700-ton nuclear explosion 900 ft. underground in Nevada (Rainier).
March, 1958	USSR announces intention to end nuclear tests.
April, 1958	US proposes meeting of scientists to study test detection.
July 1 – Aug. 21, 1958	Geneva Conference of Experts – delegates from US, Canada, United Kingdom, France, USSR, Poland, Czechoslovakia and Romania – concludes with recommendations for control system.
Aug. 1, 12, 1958	High altitude nuclear explosions over Johnston Island in central Pacific (US).
Aug. 27, 30 - Sept. 6, 1958	High altitude nuclear explosions (Argus) over south Atlantic (US).
October, 1958	Hardtack II series of underground nuclear explosions in Nevada.
October 31, 1958	US, UK, and USSR begin Conference of Diplomats at Geneva to negotiate test ban treaty. US-UK voluntary test moratorium goes into effect.
December 28, 1958	Panel on Seismic Improvement (Berkner Committee) appointed by President's Science Advisory Council (Killian Committee) to study underground test data from Hardtack series.
January 5, 1959	White House releases statement to public and to reconvened Geneva Conference claiming new data reveal Geneva control recommendations were too optimistic. US urges convening small technical committee at Geneva to consider these new calculations.
March 16, 1959	Berkner Report findings released to government.
March 30, 1959	Rand Corporation publishes report giving theoretical calculations on Big-Hole testing (declassified Oct. 20, 1959).
June 12, 1959	Berkner Report made public and simultaneously released to Geneva Conference.
August 9, 1959	Coast & Geodetic Survey, US Department of Commerce, announces improved techniques for detection of underground explosions.
Nov. 25 – Dec. 19, 1959	Scientific Conference at Geneva – US, UK, USSR – on detection of underground tests.
Dec. 19, 1959	Conference of Diplomats recesses, to reconvene Jan. 1960; UK and USSR urge reconvenement of Scientific Conference; US decides to conclude, and issue unilateral report.
Dec. 31, 1959	US test moratorium expires; Eisenhower announces that US is free to resume testing.
February 3, 1960	Foothills Conference in London (see article by Orear).
February 4,	US scientific delegates testify at Senate Disarmament Committee hearing.
February 11,	Eisenhower proposes a ban on all nuclear tests except underground explosions; rejected by USSR.
February 16,	USSR proposes a ban on all nuclear tests; permit increased number of on-site inspections.
March 16,	AEC announces plans for underground blast in Nevada next year.
March 19,	USSR accepts Eisenhower proposal with added voluntary moratorium on small underground tests.
March 28-30,	Eisenhower-Macmillan talks offer compromise short-term moratorium with rigid inspection system.

DETECTION OF TESTS (continued from page 1)

sition to discover from such a record that an otherwise unannounced explosion has occurred. But finding the unannounced explosions is exactly what an effective test-policing system would have to do.

The trouble here is that every year the recording needles of the world's seismographs wiggle in response to thousands of small and not-so-small earthquakes. So the question is: how do you determine whether the disturbance recorded by the seismograph was due to an earthquake or a bomb?

The Problem is Studied

In July 1958, after the U.S., U.K., and U.S.S.R. agreed to work on a test ban agreement, they set up a Panel of Experts to study the practicality of detecting and identifying nuclear explosions. Using the data from the single 1957 U.S. underground test, the experts came to this agreement: that a network of 180 seismic stations scattered throughout the globe would detect all nuclear explosions due to bombs greater than 10,000 tons, and distinguish such explosions from earthquakes. They agreed too that bombs of the 5000 ton size would cause noticeable tremors on the seismic records, these effects being about the same as those caused by some earthquakes. They estimated that each year, 20-100 earthquakes sufficiently strong to be confused with the effects of a 5000 ton explosion might occur. This means, of course, that such an explosion could not be clearly identified from the seismic records.

To solve this problem, the conference of experts invented a new detection scheme: the inspection team. They proposed that the 20-100 annual suspicious seismic effects could be investigated by sending a team of experts to the area of the supposed earthquake to look for evidence (such as mining operations, or surface radioactivity) of an underground nuclear explosion.

The experts' favorable report to the diplomatic conference in Geneva led to the slow but sure development of a detailed agreement for a policed ban on nuclear testing. A treaty, which is now being drafted, will set up an international Control Commission consisting of the United States, Britain, Soviet Russia, and four other countries. From headquarters in Vienna, this Commission will operate up to 170 detection stations, plus 10 detection vessels, planes, and laboratories. The Commission will have the right to send out inspectors, but the number of inspections to be permitted per year in any one country is still a matter of disagreement.

New Problems Arise

Part of the difficulty at present arises out of the fact that the scientific thinking behind the 1958 agreement was based on only one underground test. In the fall of 1958, however, the U.S. carried out a series of further tests, and the President's Scientific Advisory Committee set up a special panel of seismologists, headed by Dr. Lloyd Berkner, to study the results of these new tests.

This group of scientists worked through the winter of 1958-59, while the Geneva conference, re-

(continued on page 6)

MAKING THE DETECTION SYSTEM MORE SENSITIVE

by JAY OREAR

THE MAIN obstacle to an international agreement banning all nuclear tests has been the argument that the inspection system originally agreed upon at Geneva in October 1958, does not do a good enough job of identifying small underground explosions. The proposed monitoring system of stations can distinguish earthquakes from bombs only down to the level of 5,000 or 10,000 ton explosions.

If the detection system could be made 100 times more sensitive, explosions well below 1,000 tons (1 kiloton) could be both detected and identified. *The obvious way to increase the sensitivity of detection 100-fold is to decrease the space between seismic detectors.**

Additional seismic detectors can be unmanned, as proposed by a U.S. government-appointed committee in the "Findings of the Panel on Seismic Improvement" (Berkner Report), of March 16, 1959. Paragraph 6 of the Berkner Report states:

> . . . the augmentation of the Geneva net with an auxiliary network of unmanned seismic stations offers the possibility of major improvement in the capability to discriminate between earthquakes and explosions. For example, if such unmanned stations were spaced at 170 kilometer intervals in and adjacent to the seismic areas of the world, about 98 percent of the events as small as one kiloton equivalent, located within the network would be identified by this system . . .

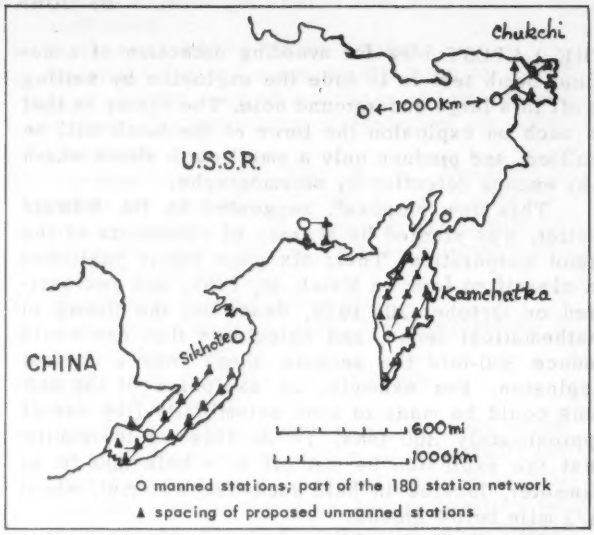
At present, this proposal offers by far the most substantial way of improving the detection situation. In spite of this, our scientists at the December 1959 Geneva technical talks did not bring up the subject of additional unmanned stations with the Soviet scientists.

There is, however, a strong indication that the system of unmanned stations proposed in the Berkner Report would be acceptable to the Russians. Last February 4 at an unofficial East-West disarmament conference in London (Foothills Conference), the Soviet delegates agreed to a public statement containing the following paragraph:

> That the US, UK and USSR negotiators at Geneva quickly agree to a treaty banning all nuclear tests with adequate inspection. We urge meanwhile that all countries refrain from nuclear testing. In an effort to break the present deadlock and answer the United States objection that small underground tests could go undetected under the present monitoring system, we recommend that the negotiators consider the addition of small auxiliary seismic stations which, if necessary, could be unmanned, on the lines recommended in the Berkner Report of March 31, 1959.

Thus the U.S.S.R. representatives agreed informally to a spacing of 170 kilometers for the unmanned, robot seismic stations in their country. (See map.) (For more information on the Foothills Conference, see the New York *Times* of February 5, 1960.

The Geneva test ban talks could probably have been brought to a successful conclusion some time ago if our side had officially brought up the subject of unmanned stations. However, the conference failed to discuss the subject in its formal sessions at Geneva. On the contrary, the administration on February 11 submitted a proposal to resume underground testing.



This map shows the distribution in Eastern Russia of several seismic stations in the 180 station network agreed to at the Geneva Conference of Experts, July-Aug. 1958. In addition, Dr. Orear suggests possible location of unmanned stations, based on the spacing of 170 km that was informally agreed to by USSR.

A number of other ways have been proposed for improving the detection of nuclear explosions. As early as 1948, scientists of the U.S. Coast and Geodetic Survey suggested that seismic sensitivity could be greatly increased by feeding the data from about 100 detectors into a central station where an electronic computor would sort out the signal from interfering "noise". Modern high-speed computors, used in connection with such a system, could quickly distinguish between signals resulting from earthquakes and explosions, according to the Berkner Report.

Another improvement is suggested by U.S. Coast and Geodetic Survey experiments conducted in April 1950.[5] Two seismographs of equal sensitivity were compared – one at the surface and the other at the bottom of a 5,000 foot mine in South Dakota. The response of the deep seismograph was about 10 times better than the surface instrument because interfering "noise" was subdued by the great depth. Even greater improvements in sensitivity may be possible with seismographs placed at the bottom of the ocean.

Summing up the possible improvements in seismic detection, the Berkner Report states, "It is the opinion of the panel that the research studies described in this document will certainly improve detection capabilities of underground nuclear detonations . . . it is important to conceive of the detection system as one which will gradually evolve with time and reach a high level of detection capability only after several years."[2]

*Since the amplitude of first motion drops off roughly as the inverse cube of the distance, a decrease in spacing of the seismic detectors by a factor of 6 will improve the detection sensitivity by a factor of 6 cubed – or better than a factor of 100.

Dr. Jay Orear is Associate Professor of Physics at Cornell University. He was one of six U.S. participants in the Foothills Conference, and is an authority on detection.

DIGGING THE BIG HOLE

By JOHN N. ONG, JR.

THE LATEST idea for avoiding detection of a nuclear bomb test is to hide the explosion by setting it off in a large underground hole. The theory is that in such an explosion the force of the bomb will be muffled, and produce only a small earth shock which may escape detection by seismographs.

This new proposal, suggested by Dr. Edward Teller, was studied by a group of physicists of the Rand Corporation. Their six page report published in classified form on March 30, 1959, and declassified on October 20, 1959, describes the theory in mathematical terms, and calculates that one could reduce 300-fold the seismic shock from a nuclear explosion. For example, an explosion of 100,000 tons could be made to look seismically like one of approximately 300 tons. To do this would require that the explosion be set off in a hole 800 ft. in diameter, located in hard rock-like material, about 1/2 mile below ground.

Although the Rand report proves, in theory, that the bomb explosion can be hidden in a hole, it does not consider the practical problem of digging such a big hole without being detected. The practical side of the matter is a problem in engineering. The following is an engineer's analysis of what it would take to dig a hole 800 ft. in diameter.

1. General:

The theory requires that the hole be dug in hard material. Blasting a hole in hard rock would be the slowest and most expensive method. Also, it would be hard to hide such a big mining operation, and to conceal the pile of excavated rock from observation. The most practical method is to wash out a hole by pumping water through a large underground salt deposit -- a salt dome. We shall therefore consider the latter procedure.

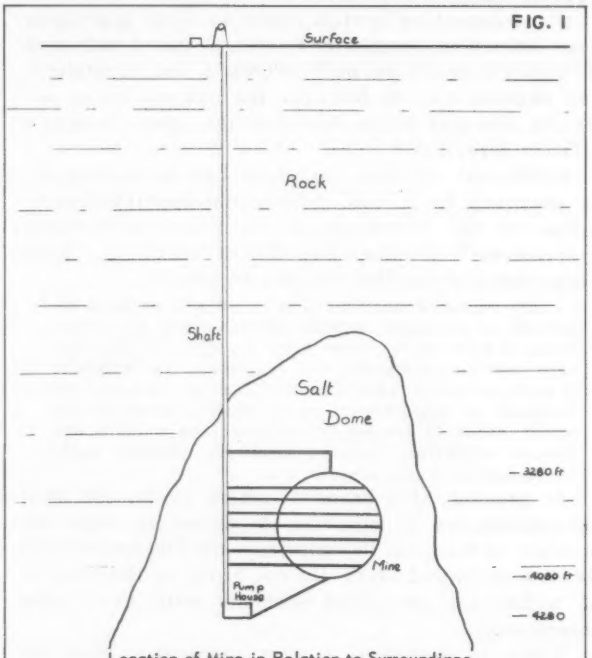
2. Location:

There are probably about a dozen suitable salt domes in the U.S. (Russia appears to have none large enough). The operation requires that about 14 billion gallons of fresh water be used to dissolve out the salt. Such a large amount of brine could only be disposed of in the sea. Accordingly, the operation must be located at a salt dome which is reasonably near a source of fresh water, and also near the sea. In the U.S., one such location is in a region west of Lake Calcasieu, Louisiana, about 20 miles north of the Gulf of Mexico. We shall assume that the operation is located at this site.

3. Mining Operations:

The underground site of the hole will be reached from the surface by means of a mine shaft. The shaft will have to be dug first -- nothing else can be done until that is finished. All the rock and salt (30,000 tons) removed in digging this shaft will have to be loaded into buckets and hauled to the surface to be trucked away. At the same time, two 30" ft. steel pipes to carry water (for the washing out operation) will have to be put in, and the sides of the shaft cemented. The best possible speed for sinking this shaft is about 10 feet per day. To bring the shaft to the level of the top of the hole will require about 328 days of work, day and night, seven days a week.

FIG. I



Location of Mine in Relation to Surroundings

At this time the necessary development of the mine can be started. The general plan is to dig horizontal tunnels through the salt dome and to build a concrete basin where the bottom of the hole is to be. (See Fig. I & II) Then, layer by layer, the salt is crushed by setting off explosives in each horizontal tunnel, and the crushed salt is washed down to the basin and pumped out of the hole.

Seven tunnels, 100 ft. apart (Fig.II) will be cut horizontal to the main shaft, and a network of passages started on each level. Workers will then start drilling holes 50 ft. long and 50 ft. apart, in the sides, top and bottom of each tunnel. These holes will be loaded with explosive. As the main shaft is continued down, each level will be opened up and developed in the same manner.

After about 420 days the mining operation will reach the eighth level, 4230 ft. below the surface, or the location of the bottom of the hole. Here a large underground room will be dug (50 x 100 x 20 ft.) to accommodate six huge pumps that will be needed to pump the brine solution out of the hole. An inclined tunnel will be dug from this room to a point at the bottom of the hole. At this point a concrete basin about 2 ft. thick and 400 ft. in diameter will be built to collect the brine washed down from the upper part of the hole. This will be a slow pro-

(Continued on page 5)

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cess (requiring about 200 days) as the entire floor (400,000 sq. ft.) will have to be completely supported by timbers. In all, 70,000 tons of concrete and 400,000 ft. of timber will be needed.

When the basin is completed, two 36 inch pipes will be installed in the lower tunnel. One of these will be connected to the end of one of the vertical pipes that come down from the surface in the main mine shaft. This pipe will be the water inlet and will rise to the lowest level in the mine. A similar pipe will be run from the bottom of the concrete basin to the pump room where it will be connected to six 4000 horsepower (hp) pumps. These will pump the brine back up to the surface through the second vertical pipe in the mine shaft.

From the start of the operation, at least 625 days will now have passed. On the surface, preparations will have to be made to pump fresh water from the lake to the mine, and brine to the ocean. This would involve 200,000 tons of pipe, buried underground for concealment, and 4 more 4000 hp pumps.

4. Removing the Salt:

The salt in the portion of the mine between the concrete floor and the lowest level would be crushed by setting off the dynamite charges packed in the holes at that level. Lake water will then be pumped into the inlet pipe, the water will dissolve the crushed salt, and the resulting brine pumped up to the surface and out to the Gulf of Mexico. When enough salt has been dissolved away, that portion between the lowest level and the next higher one is blasted

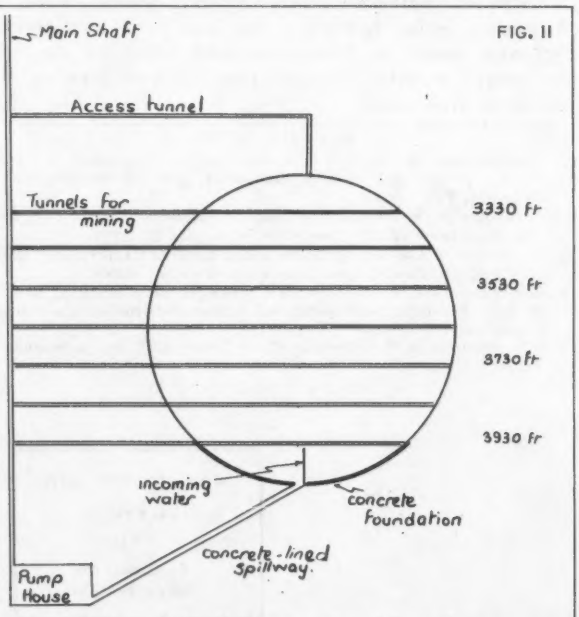

FIG. II
Side View of Mine Showing Location of Tunnels

loose and dissolved away in the same manner. In succession, all levels will be blasted loose and slowly crumble to the bottom of the mine to be dissolved by the incoming water.

This part of the operation will require a continual flow of 20,000 gallons of water per minute for 500 days. It will consume 32.5 million kilowatt hours of electrical power.

5. Important Statistics:

a. Amount of salt removed: 20,000,000 tons (about 4 times the annual U.S. production of rock salt).
b. Water required: 14 billion gallons.
c. Materials for the mine: 16,000 tons of steel pipe; 70,000 tons of concrete; 400,000 ft. of timber; 350,000 sticks of dynamite; ten 4000 hp pumps.
d. Construction: hole, 800 ft. in diameter; 7 miles of tunnel; 175,000 ft. of drill-hole.
e. Power consumed in pumping: 32.5 million kilowatt hours (enough to supply Greater St. Louis for 10 days).
f. Number of workers: about 200.
g. Estimated minimum time for completion: 3 years, 4 months.
h. Estimated cost: about $50 million.

6. Unsolved Problems:

a. Number of sites: Since there are only about a dozen salt domes in the U.S. suitable for this operation, and since each explosion will probably render the dome too radioactive for further use, the number of such tests possible is limited.
b. Hiding the hole: Because of the large amount of salt that will be washed into the Gulf of Mexico, it may be possible for interested parties to discover the operation without even setting foot in the U.S. Dumping 20 million tons of salt would increase the salt content of 200 cubic miles of sea water by 25 parts per million. Scientific techniques for measuring salt content are now so sensitive that a change in salinity of only 20 parts per million is detectable.

The water in the western half of the Gulf of Mexico where the salt domes are located, takes about two years to flow out into the Atlantic. The water that covers the continental shelf, which extends out from the shore to a distance of 40-50 miles, is renewed less frequently. So the salt that is washed into the Gulf would remain for some time near the area where it was dumped. Since the ocean depth over the continental shelf averages only about 600 feet, we would expect that during the 500 day pump-out period, an area of 1760 square miles of sea water would have its salinity raised to an extent that could be detected by a cruising vessel. Consequently, even if the great mining operation could be kept secret from foreign intelligence agents, the salt in the Gulf would give the show away.

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(Continued from page 2)
lying on the scientific estimates of the earlier Conference of Experts, continued its work. When it was made public on June 12th, 1959, the Berkner Report[2] revealed two new conclusions:

• *Analysis of the latest underground explosions showed that seismic detection was not as efficient as was previously thought.* It was more difficult to distinguish a 10,000 ton nuclear test from an earthquake than had been believed. Geneva experts had predicted, on the basis of their study of the Rainier test, that a 180-station system would distinguish all tests over 10,000 tons from earthquakes without the need for on-the-site inspection. But the Berkner Report showed that the system would pick up about 460 earthquake signals annually that could not be distinguished from 10,000 ton or larger explosions.

And whereas the Geneva experts predicted that a 5000 ton explosion seismic effect would be the same as that given by 20-100 earthquakes annually, the Berkner Report expected that 1500 such possibly confusing records would occur. All this meant that the system recommended by the Geneva experts would necessitate the investigation of nearly 2000 (rather than 20-100) suspicious events each year.

• *New seismic techniques suggested by the U.S. Coast and Geodetic Survey and others, could be used to* improve *the detection system recommended earlier by the Geneva experts.* If the improved detection system were used, the number of suspicious events needing investigation could be cut from 2000 down to 350. With further improvement -- such as a network of unmanned seismic stations -- the number could be reduced further. (See "Making the Detection System More Sensitive")

So the upshot of the Berkner Report was to leave essentially unchanged the earlier estimate of the detection problems. Detection of underground blasts is more difficult than we once thought, but advances in detection techniques can keep the problem down to manageable proportions. By the summer of 1959, the battle between detection and concealment had gone through some ups and downs, but was pretty much back where it started from -- in balance.

Can a Blast be "Cushioned"?

In the fall of 1959, the three negotiating governments recalled their scientific experts to Geneva, and asked them to consider the effects of the new information in the Berkner Report on the problem of detection and inspection. In the meantime, a new problem had come up -- the idea that nuclear explosions could be "muffled" by setting them off in a large underground hole. By the time the new scientific conference met in Geneva, they had in their hands a theoretical study by the Rand Corporation[3] which concluded that the use of a tremendous hole could reduce 300-fold the seismic shock from a nuclear explosion. (See "Digging the Big Hole")

The new scientific session met for 25 days last November and December. In that short time it was unable to come to agreement about what the new data meant. In addition to a joint report in which technical improvements of the detection system were recommended, each delegation issued a separate statement. As to the "cushioning" theory, the U.S. experts said that this would make detection much more difficult. The Russian experts felt that with improved seismic detection, the problem was not too bad, and that digging a big hole to hide explosions was not a realistic project. The British experts' views were in between.[4]

Following this scientific conference, President Eisenhower announced on December 31, that the U.S. was free to resume testing, and on March 16, the AEC announced that it had begun preparation for underground tests to take place next year. The French also entered the picture with their nuclear test in the Sahara in February.

Recent diplomatic developments since February, however, point toward a nuclear test ban treaty. Science seems to have provided adequate ways of solving the detection problem; it now lies in the realm of diplomacy.

BC & JNO

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